

Determination of the Information Content in Long-Occupied Voluntary Observing Ship (VOS) Expendable Bathythermograph (XBT) Transects.

Robert L. Molinari¹ and Gustavo Goni²

¹ Cooperative Institute of Marine and Atmospheric Studies, University of Miami, Miami, FL

² NOAA Atlantic Oceanographic and Meteorological Laboratory, Miami, FL

Project Summary

Smith et al. (1999) developed a strategy for evolving the Upper Ocean Thermal (UOT) network that considered the Ten Climate Monitoring Principles. This strategy included the discontinuation of the Low Density (LD) VOS XBT network as the Argo program coupled with satellite imagery were viewed as suitable replacements for mapping of upper layer temperature structure. However, the development and the application of the principles were accomplished in a qualitative manner with no quantitative assessment of the impact of ending the LD VOS XBT network particularly with respect to the following three monitoring principles:

- **Principle 1:** The impact of new systems or changes to existing systems should be assessed prior to implementation.
- **Principle 2:** A suitable period of overlap for new and old observing systems is required.
- **Principle 6:** Operation of historically uninterrupted stations and observing systems should be maintained.

This add-on is directed at the quantitative assessment needed to ensure that the Monitoring Principles are followed in the evolution of the UOT system. Specifically, the information content in LD lines with respect to decadal and other time-scale signals of variability will be quantified. Particular attention will be directed at decadal signals as historical observational and modeling studies have shown that oceanic variability at these time-scales could be coupled to atmospheric climate and several low-density lines have sufficient length to resolve such variability. Decisions on the value of specific lines and the desirability of continuing a portion of the LD XBT network will then be based on the monitoring principles given above. In the following the evolution of the UOT network is described (i.e., this evolution formed part of the information used by Smith et al. (1999) to design a new network). The information content that has been obtained on decadal signals from analysis of several lines is then briefly described to demonstrate the importance of these lines to climate studies.

The history of low-density sample begins with mechanical bathythermographs (MBT), which are available from World War II to the mid-1960s and provide profiles to 200-250 m. Initially XBT's, introduced to oceanography in the mid-1960s, sampled to 450 m and in the early 1970's, 750 m XBT's were introduced. MBT coverage immediately after WW II and early XBT coverage was concentrated in the vicinity of the intense boundary currents of the northern western subtropics (see Molinari, 2004). Few repeat transects were regularly occupied in the 1960's and 1970's. New sampling strategies that employed VOS, primarily commercial vessels, were developed in recognition of the need for repeat sections in climate studies. Both the Tropical Ocean Global Atmosphere (TOGA) and World Ocean Circulation Experiment (WOCE) were responsible for the institution of regularly occupied VOS transects. The resulting transition from research cruise coverage in the 1960's and 1970's to repeat transect coverage in the 1990's

is illustrated in Molinari (2004).

The data coverage from the early MBT and XBT research cruises often overlap the TOGA/WOCE transects permitting generation of upper layer (i.e., typically above 200 m) temperature time series that would include several phases of existing decadal signals. For instance, A-10 and A-7 in the Atlantic cross the Gulf Stream at about 73°W and subtropical gyre at about 30°N-35°N, respectively. By combining MBT and XBT data it is possible to generate time series from 1950 through 2005 to study decadal signals (i.e., among the longest in situ time-series available to oceanographers). Molinari (2004) generated time-series of Gulf Stream transport and position from data collected along A-10 that clearly show decadal signals as found in the NAO record and other representations of these two Gulf Stream characteristics. Watanabe et al. (1999) used XBT data collected along A-7 to demonstrate that model explanations for decadal signals in the Atlantic are not correctly simulating these features. Similar analyses are possible using data from lines in the Pacific and Indian Oceans.

The proposed two-year project has two-components. During the first year, data collected along lines that have been occupied for more than 30-years will be analyzed statistically to identify significant interannual to decadal signals. For the lines that include MBT data, records can be generated back to the late 1940's for the upper 200 m of the water column. Various variables will be analyzed (e.g., temperature on various depth surfaces, depth averaged temperature to various depths as a measure of heat content changes, etc.) to evaluate the 3-dimensional (depth, horizontal distance along the line and time) structure of the variability.

Analysis of the selected variables will allow characterization of the surface and subsurface properties of the interannual and interdecadal climatic signals. A simple averaging analysis was used to generate the time-series in Molinari (2004). The decadal signals have large enough amplitude that even this simple technique demonstrates their presence. The climatic signatures extracted with the simple statistical techniques will be compared with the known modes of climatic variability (e.g. Pacific and Atlantic El Nino, North Atlantic Oscillation, Pacific Decadal Oscillation) using conventional correlation analysis. Our analyses will characterize the subsurface structure of the known climatic modes. Confidence limits on these signals as well as their association with the climatic indices (i.e., nowcasts of the phase of a particular interannual or decadal signal) will also be estimated.

During the second year the ability of other observing systems to continue the important records will be determined. Sea height anomaly fields derived from a constellation of available altimetry missions since 1992 will be used to determine correlations between these data along XBT transects and the upper layer heat content changes from XBT data. These correlations will be used to determine (1) the ability of the satellite data to replicate decadal signals (the 12 years of data include important phases of decadal signals, Molinari, 2004), (2) the ability of the altimetric data to fill spatial and temporal gaps in the in situ observations, where needed, and (3) regions where in situ can provide the only measure of decadal signals (e.g., regions where steric effects mask thermocline effects on sea surface height anomalies).

Accomplishments

This 'annual report' provides accomplishments in developing and applying the generic software that can be used to perform analyses on all the selected lines.

Applying software:

- (1) The software to compute simple statistical properties such as the mean section, standard deviation, amplitude and phase of the annual and semi-annual harmonics, etc. has been completed and has begun to be applied to Atlantic sections. An unexpected finding, was that many of the numbered lines in the Atlantic were not occupied by individual ships but exist only because several other lines cross the nominal line. Since these latter lines are not likely to be occupied in the future (i.e., regular shipping is probably not available), analysis will not be applied to the “imaginary” transects.
- (2) To date high density lines in the Atlantic have been reviewed. A7, 8, and 10 all include decadal signals related to the subtropical gyre (A7 and 10), the Gulf Stream (A10) and the tropical Atlantic (A10) justifying continuation. However, it should be determined if the high density resolution of these lines is capable of resolving the signals found in the low density sampling.
- (3) At present, there are no lines in the subpolar Atlantic. Lines A1 and A2 have been discontinued because of lack of funding. The importance of the subpolar gyre to the meridional overturning circulation argues for resumption of a line in the subpolar Atlantic.
- (4) A website has been developed and will serve to display all the products generated from this project.

Additional software developed:

- (1) Software to compare sea level anomalies generated from altimetric observations to upper ocean heat content has been developed. The comparisons will be applied to the long-occupied low density lines to determine which portions of the global ocean require in situ observations to study surface variability and to identify areas where model and altimetric measurements of sea level require particular care.
- (2) Considerable decadal variability has been observed in upper ocean characteristics. An important question is what causes this variability, in particular switching from one phase of the signal to another. Band pass filtering of the upper layer temperature data has been used to identify switching in the North Atlantic. However, questions exist relative to the results of this analysis (i.e., different latitudes were used, in regions where different variability might be active). Band pass filtering subroutines isolating the decadal period have been developed and will be applied to sections that exhibit decadal signals (e.g., subtropical and subpolar Atlantic and Pacific). The results of this analysis will be applied to model results in an attempt to identify switching dynamics.
- (3) Programs that correlate time series from different will be developed to study the scales of upper layer temperature variability.

Deliverables: One year from receipt of funding, 31 May 2008

- (1) Characterization of the global upper layer temperature structure and variability from those lines with sufficient data to generate time-series.
- (2) Nowcasts of the state of the ocean along these lines with respect to known decadal climate signals (i.e., the phase of the PDO, NAO, TAV, etc.) will be generated.
- (3) Identification of low-density lines with sufficient information content to justify continuation.
- (4) Identification of regions where satellite altimetry observations do not provide an

adequate measure subsurface structure.

- (5) Explanation of the switching mechanism in decadal signals
- (6) Website illustrating all the products generated during the period of this proposal.

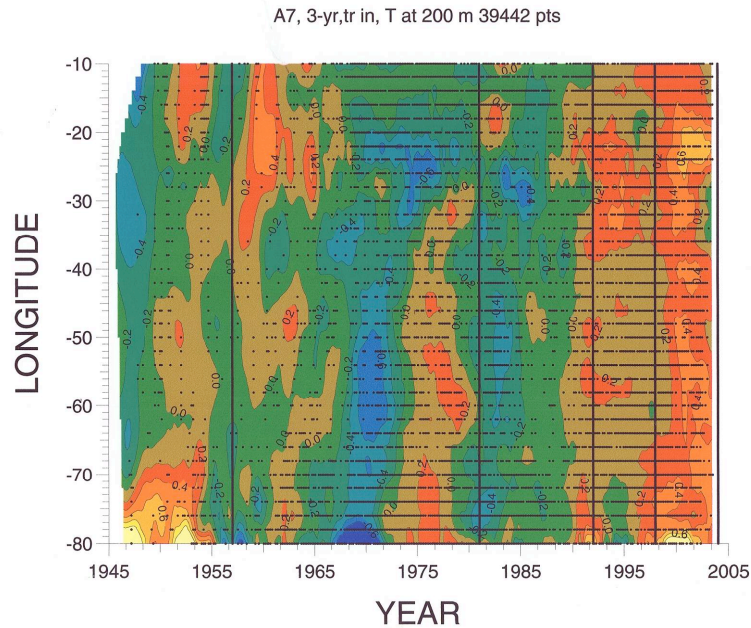


Figure legend: Time (in years) versus longitude along low and high-density line A7 (which extends from Miami to the Mediterranean) plot of temperature anomaly at 200 m. The record pre-1967 was developed from mechanical bathythermograph data and post-1967, expendable bathythermograph data. Units are degrees C. The vertical lines represent years considered by Bryden to develop his hypothesis of declining meridional overturning circulation, MOC, (i.e., positive anomalies indicate a deeper thermocline and more intense subtropical gyre). Bryden hypothesized that the weaker subtropical gyre increased northward heat flux. The contours relative to the years of data indicate that a stronger MOC would have been observed earlier in the record if a shift of a few years in sampling occurred (i.e., higher frequency variability brings into question the finding of a weakened MOC).

References

1. Davis et al. (1992) The autonomous Lagrangian circulation explorer (PALACE). *Journal of atmospheric and Oceanic Technology*, 9, 264-285.
2. Molinari, R.L. (2004) Annual and decadal variability in the western subtropical North Atlantic: Signal characteristics and sampling methodologies. *PROGRESS IN OCEANOGRAPHY*, 62, 33-66.
3. Roemmich et al. (1999) Argo: The global array of profiling floats. In: *Oceanobs 99*, Saint-Raphael, France, Smith and Koblinsky, editors.
4. Smith et al. (1999) The role of XBT sampling in the ocean thermal network. In: *Oceanobs 99*, Saint-Raphael, France, Smith and Koblinsky, editors.
5. Watanabe, M., M. Kimoto, T. Nitta, and M. Kachi (1999) A comparison of decadal

climate oscillations in the North Atlantic detected in observations and a coupled GCM. JOURNAL OF CLIMATE, 12,2920-2940.